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Evaluation of Bridge Rail Cracking – N. Ohio St. Overpass Salina Kansas

Report to
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by
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CTLGroup Project No. 210706

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EVALUATION OF BARRIER RAIL CRACKING – N. OHIO ST. BRIDGE

by

S. T. Wyatt *
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1 SUMMARY

CTLGroup was retained by the City of Salina, Kansas to evaluate the N. Ohio St. Bridge in Salina KS. The bridge is currently under construction and is exhibiting excessive cracking in the west parapet at the fence anchorage locations. Additionally, transverse cracks were observed in the sidewalk overhang at the east fence anchorage locations. CTLGroup implemented an inspection and structural evaluation program to assess potential causes of the parapet cracking, and identify potential repair procedures. The inspection focused on the bridge rail cracking of the west parapet and cracking in the east sidewalk overhang.

2 INTRODUCTION

2.1 BRIDGE DESCRIPTION

The N. Ohio St. Bridge is a prestressed concrete girder superstructure with a composite reinforced concrete deck on conventional reinforced concrete substructure. Decorative fencing is attached to the parapet on the west side of the bridge and to the sidewalk overhang on the east side. The west fence anchorage detail consists of 3 -19.1mm A307 U-bolts embedded approximately 140 mm into the concrete rail with No. 19 bars passing longitudinally through the u-bolts. The east fence anchorage detail consists of 6-19.1mm A307 bolts passing full depth through the overhang with anchor plates on each side of the concrete. The east overhang connection consists of 6-19.1mm A307 bolts passing full depth through the overhang with anchor plates on each side of the concrete.

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2.2 METHODOLOGY

CTLGroup utilized a multi-faceted inspection and analysis methodology to evaluate the bridge. The inspection included review of existing drawings, design calculations, inspection reports, material submittals, and other correspondence; a hands-on visual inspection and crack mapping to highlight areas of concrete distress; and computer modeling and calculations to verify design forces and capacities. The following documents were reviewed:

- 85 K-8307-01 contract drawings
- HNTB design calculations
- Kansas Department of Transportation Standard Specifications
- KDOT Special Provisions
- Steve Johnson Companies shop drawings
- Construction photographs of fence installation
- Daily Construction and Field Diaries thru 1-19-07 and 1-25-07 Respectively
- Concrete Mix Design and Strength Test Results

2.3 ACCESS/LIMITATIONS

Access to the west parapet was provided by a lane closure of the right south bound lane and access to the east fence anchorage locations was available via the sidewalk. The outside face of the west parapet was accessible via a manlift positioned on the Union Pacific property under the bridge. Approximately 9 anchorage locations over active rail lines on the outside face of the west parapet could not be viewed up close, due to restrictions imposed by the railroad.

3 RESULTS

The field inspection work was completed on July 19, 2007 by Mr. Scott Wyatt. Also present were Mr. Ben Levinson of the City of Salina and City traffic control personnel. The following sections describe results for the scope of work performed.

3.1 DOCUMENT REVIEW

CTLGroup was provided with various documents pertaining to the bridge design and construction. The following observations, relevant to determination of cause of cracking, were made, with regards to the documents' contents:

- The forces used in design of the anchorage did not consider group loadings that included temperature forces
- The fence anchorage capacity was determined in accordance with the PCI Design Handbook 4th Edition.
- The calculations checked pull-out of a single anchor and tensile failure of a single anchor
- The design calculations and Details G and P on Sheet 136 of the contract drawings identify the u-bolts as 5/8" and 15.9 mm diameter, respectively
- The shop drawings and Section B-B on sheet 136 of the contract drawings identify the u-bolts as 19.1 mm diameter
- No information was provided in the contract documents with regards to required fence installation procedures

3.2 FIELD EVALUATION

A comprehensive visual inspection was performed of the west parapet. Rail cracking was mapped at 71 anchorage locations on the roadway face of the parapet, and at 62 locations on the outside face of the rail. A total of 22 anchorage locations were noted to exhibit horizontal cracking below the anchorage zone, see Figs. 1 and 2. The crack widths varied from 0.005 in. to 0.25 in. A cover meter was used to evaluate the depth of the anchor bolts at a random sample of anchorage locations. Depth of the u-bolt embedment into the parapet was estimated to range from 4 in. to 5 ½ in.

Figs. 1 and 2 – Parapet Cracking at Roadway Fence Anchorage

3.3 COMPUTER MODELING AND ANALYSIS

A finite element analysis of the roadway fence was created to analyze the reactions at the fence base; see Figs 3 and 4. The AASHTO Group V load combination was used for determination of the reactions at the fence base. Based on the fence installation occurring in February, a temperature gradient of 40°F was applied to the model to obtain thermal forces.

Although the anchor plates were detailed with slotted holes the connection was conservatively assumed fixed. This assumption was based on two primary factors. First, the original design model for the fence system assumed complete fixity of the fence anchorages and the intent of CTL's analysis was to approximate the original design. Secondly, considering the design life of the structure, length of the fence, unique geometry of the individual units, steel plates bolted to concrete, total number of anchorages, configuration of slip joints, and environmental exposure, it is our opinion that the anchorage should be analyzed for a fixed condition. This is part due to corrosion restricting or preventing longitudinal movement. It should be noted that rust was already visible, as shown in Fig. 1, on at least one slip joint during CTL's site visit. Table 1 lists a comparison of the CTL analysis and original design calculations for the fence reactions transferred to the anchorage. Additionally, anchorage capacity was calculated in accordance with ACI Appendix D for comparison against the design calculations. The accepted procedure of ACI appendix D accounts for the presence of confinement steel in determination of the phi factor. See Table 2 for results of the anchorage capacity calculations.

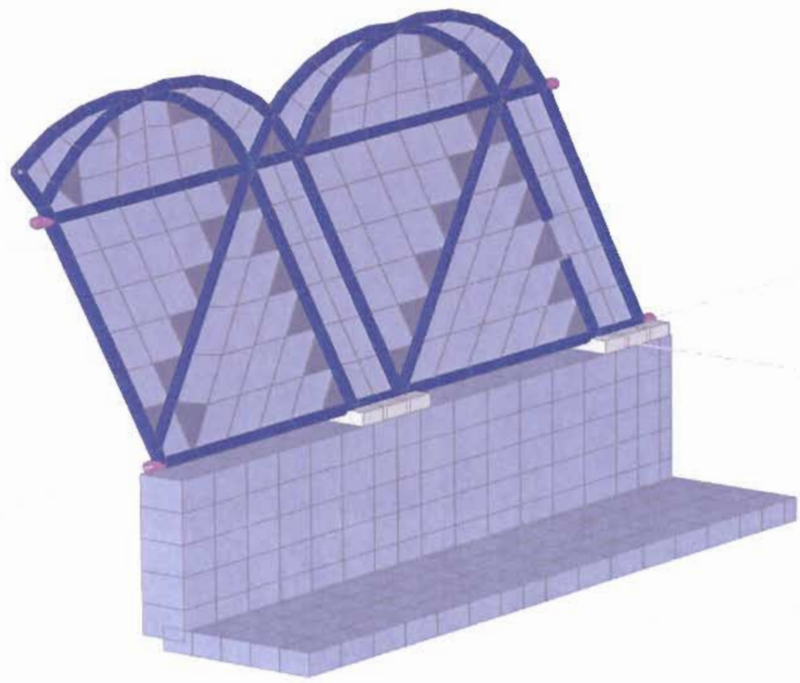

Fig. 3 – Finite Element Rendering of Pedestrian Fence Interior Unit

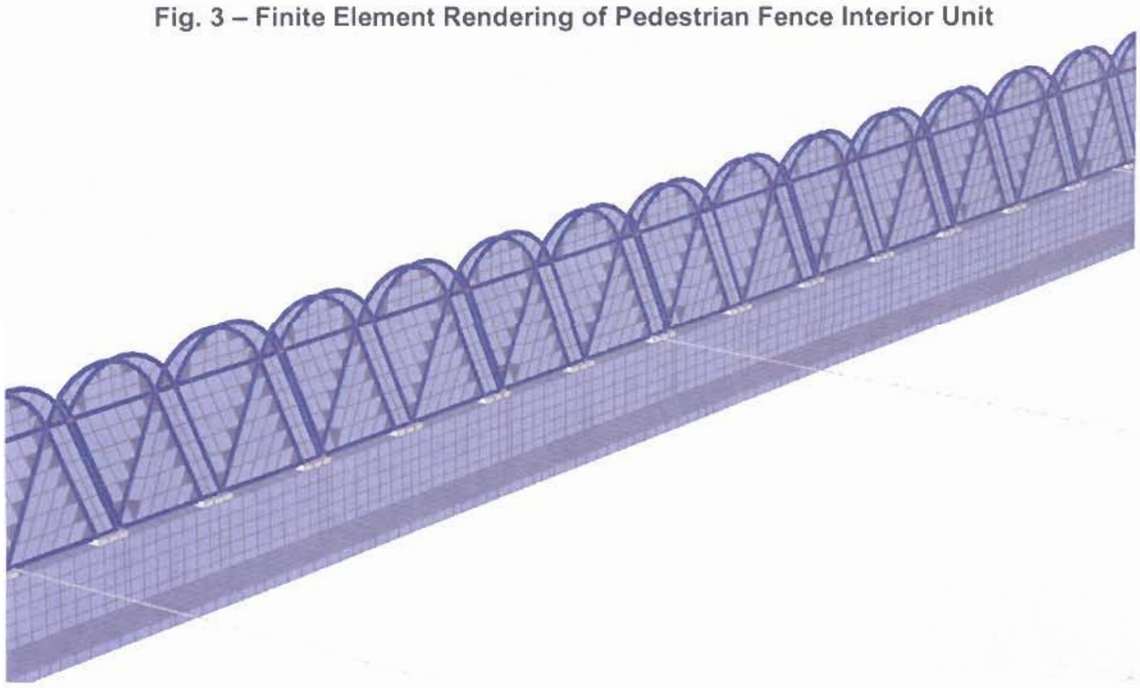

Fig. 4 – Finite Element Rendering of Pedestrian Fence

Table 1 – Comparison of Design and Analysis of Applied Fence Reactions

	Original Design – Group II	**CTL Analysis – Group V**
Vertical - Tension(+)/ Compression(-)	-2.6 kN	3.1 kN
Transverse Moment	6.0 kN-m	7.0 kN-m
Longitudinal Moment	0.0	9.1 kN-m
Transverse Shear	-4.4 kN	-4.5 kN
Longitudinal Shear	0.2 kN	110.0 kN
Maximum Calculated Tension per Bolt		
	7.5 kN	41.1 kN

Table 2 – Comparison of Capacity and Factored Loads of Fence Anchorage

Check	**Original Design Capacity - PCI 4th Edition**	**CTL Analysis Capacity - ACI Appendix D**	**Factored Load**
Single Bolt Tension	$\phi Pc = 46.0$ kN	$\phi Npn = 29.8$ kN	41.1 kN
Transverse Shear	N/A	$\phi Vn = 112.5$ kN	4.5 kN
Longitudinal Shear	N/A	$\phi Vn = 225.0$ kN	110.0 kN
Shear-Tension Interaction	N/A	$Nua/\phi Nn + Vua/\phi Vn < 1.2$	1.9

4 CONCLUSIONS

4.1 WEST BARRIER RAIL

Based on our field evaluation, review of design documents, and computer modeling and analysis, we attribute the horizontal cracking around the anchorages of the concrete barrier rail to overstress of the anchorage connection. The vertical intermittent cracking of the barrier rail is attributed to restrained shrinkage of the parapet. The anchorage is determined to be overstressed under two conditions, tension pull-out of the bolts, and combined shear-tension interaction. The concrete failure was likely caused principally by design factors:

- The fence anchorage design did not account for thermal forces transferred to the parapet from the fence system. The geometry, stiffness, indeterminacy, and restraint inherent in the unique fence architecture introduced significant additional loads on the connection and the parapet, which were not considered in design.

- In determining capacity of the anchorage system, original design calculations did not consider all of the possible loading conditions and failure modes; particularly group failure and interaction of combined tension and shear.

- The u-bolts were assumed to behave as headed studs in calculating anchor pull-out capacity. At the date the design calculations were completed, the PCI Design handbook 5th Edition and ACI Building Code Requirements for Structural Concrete 2002 were available. Both of these references contain design equations for calculating capacity of hooked bolts which more closely approximates the actual condition.

- Design drawings did not specify slotted base plates (although slots were detailed in the shop drawings)

- Because the thermal forces were not considered in design, the anchorage fails to meet AASHTO requirements stipulating that the design of all members and connections must be such to resist all applied loads.

A number of additional factors that could have potentially caused or exacerbated the cracking have been considered. These are discussed below.

Over-tightening of the Anchor Bolts - The observed cracking is indicative of a group failure. Inspection observations noted that the anchor bolts were tightened individually. Over-tightening of anchor bolts individually would not produce the observed cracking patterns. Additionally, if the cracking was due primarily to over tightening of the bolts, the cracking would have appeared immediately. It is possible that over-tightening of the anchors could increase the fixity of the joint and prevent longitudinal movement thereby imposing unexpected stress in the anchorage. However, the original fence model identified these joints as fixed and no notes were provided on the drawings identifying the anchorage as hand-tightened only.

Installation Procedure – No guidance or procedures for the fence installation were provided for CTL's review. Without instrumentation in the concrete, it is impossible with the given information to determine what stresses were induced in the parapet during fence installation. However, it is unlikely that the setting sequence induced the high tensile stress in the concrete that caused the observed cracking because the cracking is not reported to have occurred immediately during installation.

Concrete Consolidation Under the Anchorage – No information has been found by CTL that could correlate specific anchorage locations where consolidation problems occurred to locations with the observed horizontal cracking. The failure patterns do not indicate under-consolidated concrete as a primary cause of the cracking.

Surface Treatments – Surface treatments are unlikely to have contributed to the observed cracking.

4.2 EAST OVERHANG

The connection on the east overhang provides a clamped type connection where tensile load is transferred through the anchor plates via the anchor bolts. This connection detail does not have any of the physical characteristics of the west connection that would make it prone to a pull-out failure of the concrete. Analysis indicates it is improbable that the same cracking phenomenon will occur in the east fence connection. Transverse cracking observed in the east sidewalk overhang is most likely shrinkage cracking due to restraint of the sidewalk overhang being placed compositely with the older roadway deck overhang. Shrinkage of the newer sidewalk concrete was restrained by the older roadway deck concrete. Because the anchor bolts provide a weak spot in the concrete overhang, it would be expected that many of the cracks would pass directly through anchor bolt locations.

5 RECOMMENDATIONS

Cracking on the west rail indicates an overload condition in the anchors. This overload most likely has reduced the strength of the connections. Precautions should be taken to temporarily brace the west rail fence attachments where horizontal cracking is occurring to assure safety of the west side attachment under lateral loading. Because the concrete has experienced significant cracking in many locations, retrofit of the anchorage may not be possible and replacement of the damaged concrete may be necessary. To properly anchor the fence system to the bridge superstructure without causing a failure of the concrete parapet, one of the following should be provided 1) the anchorage should be re-designed with enough capacity to resist all loads transferred from the fence system, or 2) the connection should be detailed to accommodate the applied design forces rather than transfer them to the concrete parapet. Due to the lack of sufficient capacity of the anchorage and resulting tensile failure observed in the concrete, we do not recommend a redesign or retrofit of the anchorage and repair of the concrete without removing the fence. CTLGroup can assist the City with preparation of more detailed repair concepts and repair plans.